4

Corneal Topography

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To establish a correct fitting relationship, a contact lens should be designed to approximate the entire anterior corneal surface. For this reason, it is necessary to measure accurately the curvature of the corneal surface, not only in the center but also in the paracentral area and the far periphery. Unsuccessful contact lens patients sometimes are found to have lenses that do not approximate the paracentral area of the cornea. A knowledge of corneal topography is thus important in fitting contact lenses. It is also important in kerato-refractive surgery. It is possible that the refractive changes, resulting from kerato-refractive surgery may be dependent on the original corneal topography. The following discussion will review the definition of corneal contour measurements and the fitting of contact lenses in relation to peripheral corneal topography.

For more than 100 years, investigators have studied the shape of the cornea. As a generality, the curvature of the central area of the cornea is spherical, and the rest of the cornea is aspherical. The aspherical portion of the cornea flattens progressively from the paracentral area to the periphery. The keratometer measures only the curvature of the central region. The aplanatic,[1] or aspherical, curvature may be measured by topogometry,[2] photokeratoscopy,[3,4] or corneoscopy.[5-7] The paracentral flattening of the cornea is important in fitting contact lenses since the mid-periphery of the cornea is the bearing area for a contact lens.

DEFINITIONS

ZONES (Fig. 4-1)

Apical Zone (AZ)

DESCRIPTION

The AZ (apical cap, corneal apex) is the central area of the cornea over which the curvature (as evaluated by ophthalmometric readings) does not vary by more than one diopter.[8,9]

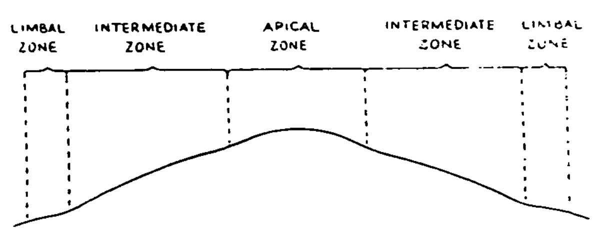

Fig. 4-1. Classification of the cornea into zones.

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SIZE AND SHAPE

A major advance in recent years has been the introduction of the topogometer.* By using this instrument, one can determine the size and shape of the AZ. The use of the topogometer has also led to a new concept in fitting contact lenses. In fitting nongas-permeable hard lenses [conventional poly (methyl methacrylate) (PMMA)], it is desirable for the lens to be as small as possible. If the lens is too small in relation to the apical cap, however, the lens will decenter. By using the topogometer, one can determine the size of the apical cap of that particular patient. A contact lens that is designed to be 1 mm larger than the apical cap theoretically will result in a good fit. This is the LD + 2 fitting technique. (LD is the abbreviation for *least diameter*, and 2 refers to 2 mm. The lens is 1 mm larger on each side, for a total of 2 mm.)

Intermediate Zone (IZ)

The IZ is the area of the cornea extending from the AZ to the limbal zone (LZ). In some instances, the IZ is perfectly spherical; in this case, the cornea is referred to as a *round* cornea. In other instances, the IZ is flattened; the cornea is then referred to as an *aplanatic* cornea.

The IZ is important in the design of contact lenses, since ideally the periphery of the contact lens should approximate the IZ. This is especially important in the design of keratoconus contact lenses and toric contact lenses.

Limbal Zone (LZ)

The LZ is the area at the junction of the cornea with the scleral sulcus.[8] The cornea flattens in the IZ, anterior to the furrow, marking the scleral sulcus.

* The topogometer is an instrument that is attached to the keratometer to provide a graduated, movable point source of light. The topogometer has a graduated scale that indicates, in steps of 0.1 mm, the decentration of the visual axis of the cornea from the optical axis of the keratometer.

As the patient's eye sights the movable light source, the patient's visual axis can be decentered from the optic axis of the keratometer. The eye is moved slowly in a horizontal direction until flattening is noted. The point at which flattening is first noted is the limiting margin of the diameter of the apex in the horizontal meridian. To determine the diameter in the opposite major meridian, that is, the vertical meridian, the keratometer is ro[illegible]ed 90° and the procedure is repeated. That reading is the limiting [illegible]gin of the diameter of the apex in the vertical meridian.

The amount of mo[illegible]ent over the curvature in any one meridian that does not result i[illegible] [illegible]nge is a measure of the diameter of the surface. The greater the true spherical area of the cornea, the greater will be the amount of movement possible before any change in the corneal curvature is noted. In irregular corneas, the curvatures are consistent only over a very small range of decentration. Similarly, one can evaluate situations in which the AZ is decentered from the geometric center. In these instances, eccentric positioning of the corneal contact lens occurs because of the tendency of the lens to center over the apex. The topic will be further reviewed in Chapter 17.

PRINCIPAL CORNEAL MERIDIANS

The principal corneal meridians are the flattest and steepest corneal meridians of the major astigmatic axes of the cornea. These two meridians are usually 90° apart. Most often the horizontal meridian is flatter than the vertical meridian, producing with-the-rule astigmatism.[9] Although one expects the major corneal meridians to intersect perpendicularly, these two axes may be markedly disparate in high astigmatism or keratoconus.

OCULAR SURFACE CENTERS

Visual (Optical) Center

The visual center is the point of the cornea through which the visual axis passes.[4] The visual center can be located by noting the corneal light reflex while the patient fixates a point light source and the visual axes of the examiner and the patient are coaxial.

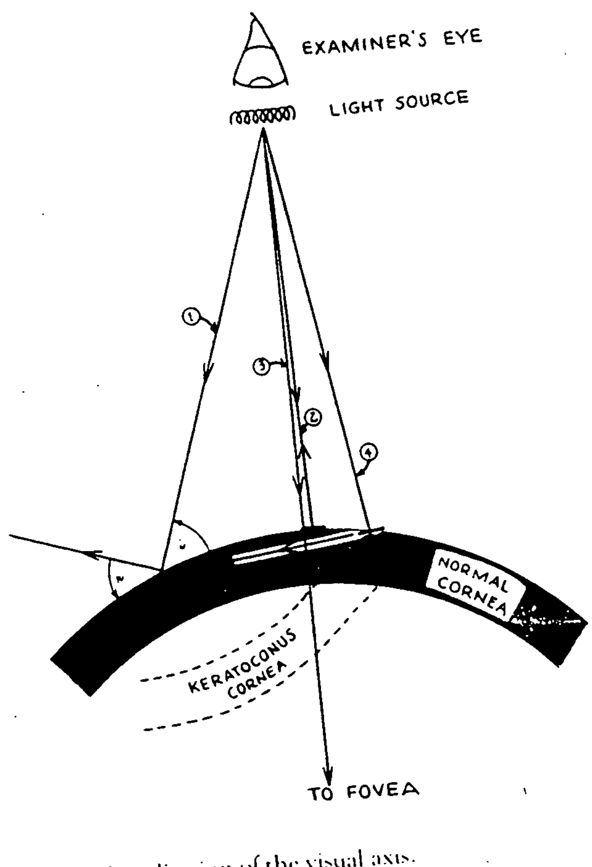


Fig. 4-2. Localization of the visual axis.

The correct localization of the optical center has become important in the radial keratotomy operation. In spherical, or almost spherical, corneas, the visual axis is usually easily located. In the instance of a highly irregular corneal surface, however, greater difficulty is encountered in correctly identifying the visual axis.* This is illustrated in Figure 4-2. If this is not appreciated, the "optical center" may be grossly misplaced when the trephine is applied. A corneoscope photograph (Color Plate 4-1) of a keratoconus with a markedly decentered corneal cap illustrates this point. The small arrow points to the visual axis (the visual axis transverses the center of the pupil). The white dot corresponds to the high point (vertex) of the cornea and is in front of the large arrow. The high point on the cornea indicates the location of the light reflex. Thus it is obvious that the light reflex does not correspond to the visual axis. This same case, when analyzed by computer graphics (Fig. 4-3), results in a three-dimensional view; again, the visual axis does not correspond to the light reflex. The small arrow in Figure 4-3 corresponds to the visual axis; the large arrow and white dot indicate the vertex as seen in Color Plate 4-1.

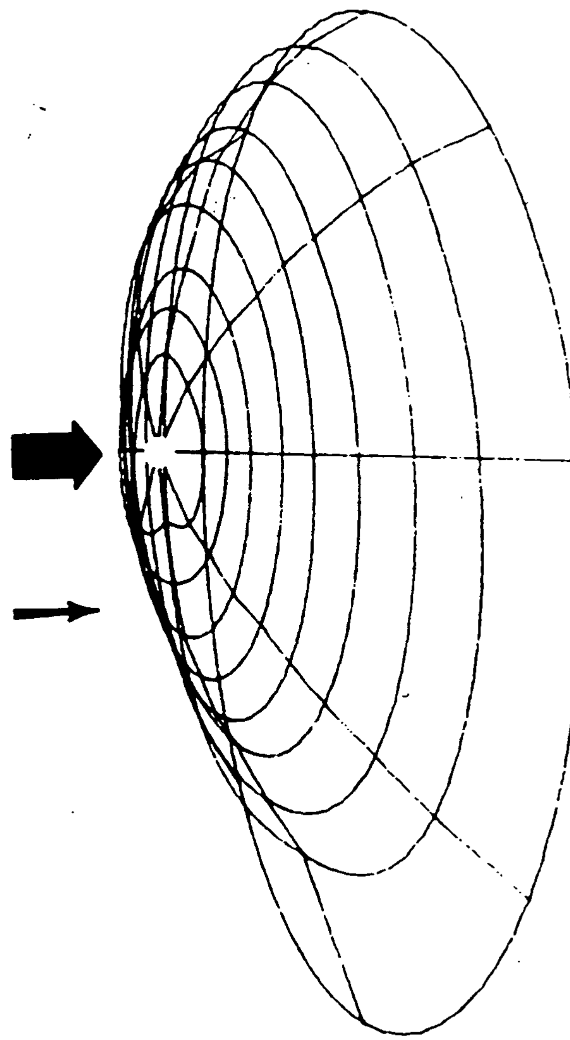


Fig. 4-3. Computer graphics of keratoconus shown in Color Plate 4-1. Note the marked corneal identation and irregularity. Small arrow points to visual axis. Dot corresponds to high spot on cornea.

Geometric Center

The geometric center is the point at which the longest horizontal and vertical surface arc lengths intersect.[8] The geometric center is frequently temporal to the visual center because of angle kappa.

SPHERICAL ABERRATION

Spherical aberration refers to a phenomenon in which the very peripheral rays, because of the greater refractive power of the periphery of a curved surface, come to a focus before the paraxial rays (Fig. 4-4). If one considers the cornea as a spherical curved surface, rays that are incident to the far periphery of the cornea come to a focus in the vitreous, not on the retina. In effect, the periphery of a perfectly spherical cornea has excessive power so that rays that are incident to the periphery of the cornea are overcorrected, resulting in visual disturbance. Fortunately, in many cases, there is slight flattening of the peripheral cornea. In such instances, the peripheral flattening compensates for the excessive peripheral refraction.

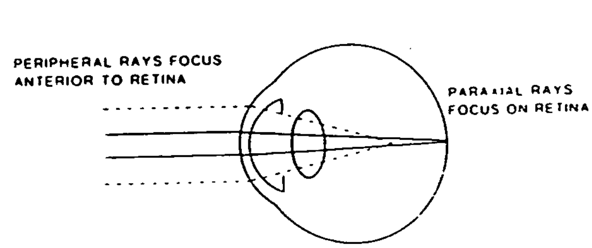


Fig. 4-4. Round cornea: increased spherical aberration

* See Appendix A, "Localization of Visual Axes."

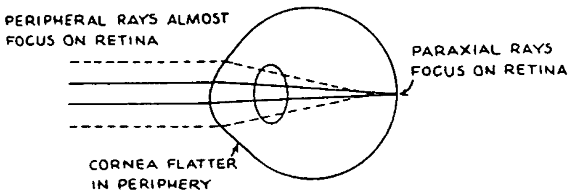


Fig. 4-5. Aplanatic cornea: Decreased spherical abberration.

When the cornea is aplanatic (i.e., steep in the center and flat in the periphery), a lesser refraction occurs at the peripheral cornea, so light rays come to a focus on the retina (Fig. 4-5). Peripheral corneal flattening is the ideal situation.

METHODS OF MEASURING CORNEAL TOPOGRAPHY

The curvature of the cornea can be measured with several instruments, including the ophthalmometer (keratometer), topogometer, photokeratoscope, and corneoscope. Each of these will be reviewed.

OPHTHALMOMETER (KERATOMETER)

The ophthalmometer is the instrument most commonly used to measure corneal curvature. If one were to select the instrument that most practitioners use in their office practice, there is no doubt that the keratometer would be the first choice. It has many disadvantages, however. These will be reviewed.

Measurement Limited to the Central Area of the Cornea

As routinely used, the keratometer measures only a small area: the central 3-4 mm of the cornea. It does not measure the curvature of the periphery of the cornea. The instrument can therefore be used only to evaluate the central cornea.

Peripheral keratometric readings can be made by having the patient rotate the eye so that the mire is incident to the peripheral area of the cornea. Since the exact location of the center of rotation of the eye is unknown, however, the reading may be in error and is not reproducible. Furthermore, the incoming light striking the periphery has an oblique incidence. This results in a power measurement that cannot be compared to an apical measurement. Peripheral keratometric readings with the ophthalmometer are therefore not accurate.[4]

Error Caused by Slight Ocular Rotation

If the mire is directed to the center of the corneal surface so that it is perpendicular ("normal") to the cornea, the mire will be regular in outline, indicating that the corneal surface is spherical. If the eye rotates slightly so that the mire is directed to the intermediate area, however, it will have an oblique incidence; thus the mire will be irregular in shape, indicating that the corneal surface is aspherical. A spherical surface (e.g., the corneal apex) will thus appear to be aspherical if the eye rotates so that the mire does not have a perpendicular incidence to the eye.

Inability to Evaluate the Sphericity of the AZ

The ophthalmometer is designed to measure a spherical surface. Actually, it measures the radius of curvature of two small points 3 mm apart.[10] It is assumed that the area between these points is a spherical surface and that a circle of fixed radius passes through both points. This may not always be the case, however. If one compares the cornea in Figure 4-6 (left) with the cornea in Figure 4-6 (right), chord A is equal in both corneas, so it is assumed that they are both spherical surfaces of the same curvature. In fact, the cornea in Figure 4-6 (right) could have a very irregular surface due to a deformity (represented by the star). It would still be seen, however, as a spherical surface. As an extreme example, even if a central corneal facet were present in the center of the cornea between the two mire images, the cornea would still be assumed to have a spherical surface as measured by keratometry.

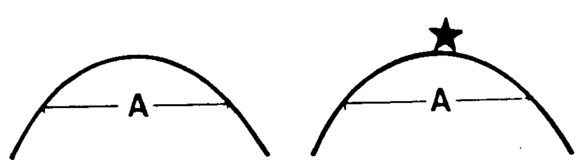


Fig. 4-6. Chord length A is a virtual image measured by the keratometer. Only two reflecting points delimit the chord. Any irregularity of the corneal surface between the reflected points will not be appreciated. The star, or any other topographic aberration, will be overlooked if it is small enough to fall within chord length A.

Inadequate Size of the AZ in the Instance of a Steep Cornea

The chord length required for the reflection of the mires is a function of the radius of curvature of the surface. A flat cornea (36 D) requires 4 mm of reflecting surface for visualization of the corneal mires.[8] By contrast, a steeper cornea requires a smaller reflecting surface. A 52-D cornea requires only 2.77 mm of reflecting surface to visualize the mires.[8] If the AZ is small, therefore, one mire will be reflected from the AZ and the other mire will be reflected from the IZ. The keratometer averages these two point reflections, so the radius is not very accurate.

Measurement along the Visual Axis Rather Than the Geometric Axis

Since the patient gazes into the instrument, the measurement is made along the visual axis. The visual axis, however, may not coincide with the geometric axis. The visual axis is often nasal, and the geometric axis is often temporal. The curvature at the visual axis is flatter, whereas that of the geometric axis is steeper.[6] When the patient gazes into the ophthalmometer, the reading may therefore, indicate greater flatness than actually exists.

Lack of Inclusion of the Principal Meridian in High Astigmatism

The measurement of the AZ may not include the area of one of the principal meridians of a highly astigmatic cornea. A highly astigmatic cornea occurs, for example, following a corneal laceration.

Diffraction of Light

The diffraction from the wave length of light sets a limit of about 0.2 D on the precision of the keratometer. Separation of wave lengths by less than one-quarter the wave length of light makes them indistinguishable from each other.

This problem is partially aggravated by the use of small-mire keratometry. Small-mire keratometers, which measure the cornea over a shorter chord length, have a lower resolution of approximately 0.5 D.[9]

Varying Dioptric Power Readings with Different Types of Ophthalmometers

When one compares readings from various types of ophthalmometers, the readings are sometimes different for the same patient. This disparity is due to the optics of the keratometric scale conversion. As will be discussed in Chapter 17, the instrument measures only the radius of curvature; it does not measure the dioptric power. The dioptric power is determined by a formula, a component of which is the refractive index of the cornea. The refractive index of the cornea, which is referred to as the *keratometric index*, is a hypothetical value based on various assumptions of corneal curvature. Various manufacturers assign different keratometric indices to their ophthalmometers. If one uses different types of ophthalmometers, one can therefore, obtain different dioptric readings on the same patient.

Observer Accommodation

If the eyepiece is not properly focused, the observer will accommodate, resulting in an inaccurate measurement.[10]

Need to Accept a Wide Range of Tolerance

Brungardt[11,12] attempted to determine the reproducibility of the keratometer by performing keratometric readings on the surface of a steel ball of known curvature. The Bausch and Lomb keratometer was used. Three steel balls were measured randomly throughout the day in 11 different sessions over a 30-day period. During each session, five readings were made and averaged for each meridian. A second observer read the radii measurements and changed the settings before the examiner attempted a second reading. The total range of error using this technique was 0.37 D. Brungardt concluded that "any single reading may be in error 0.37 D due to the operator and/or instrument." Keratometric measurements demonstrated the range of error for the horizontal meridian to be 0.37 D and for the vertical meridian to be 0.75 D. Brungardt repeated this study with the American Optical keratometer and reached the same conclusion. If the subject is measured, using either of these ophthalmometers, deviations must exceed 0.37 D in the horizontal meridian and 0.75 D in the vertical meridian in order to be significant.

TOPOGOMETER

Topographic analysis of the cornea with the topogometer suffers from the same inherent errors that are present when one uses the keratometer alone. Asphericity of the peripheral cornea cannot be accurately measured by the keratometer because of the averaging of mire positions by adjacent steep and flat corneal curves.[6,13]

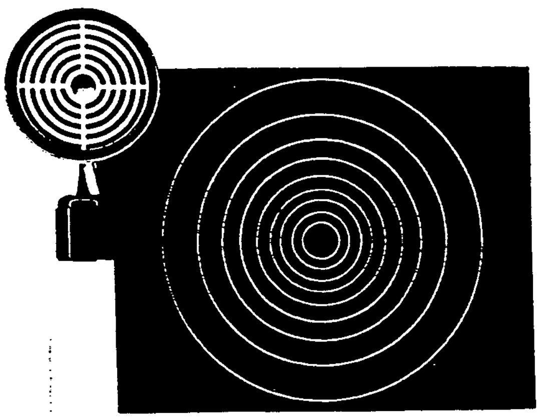


Fig. 4-7. Photokeratoscope. Lighted Placido disc on the left has equal ring spacing. This is reflected as diminishing ring spacing from a round surface. The reflection from the cornea on the right demonstrates increasing ring spacing from the center to the periphery, but the reflected rings from such a round surface are equally spaced. Subtle astigmatic changes will result in unequal spacing and distortion of the round pattern.

PHOTOKERATOSCOPY

Whereas the keratometer measures the central 3–4 mm of the cornea, the photokeratoscope (Fig. 4-7) measures the entire area of the cornea, that is, 9–12 mm.

The photokeratoscope, invented by Antonio Placido,[14] was subsequently popularized by Dr. Allvar Gullstrand, who is universally credited with its development.

Advantages

The advantages of photokeratoscopy are discussed below.

ABILITY TO EVALUATE A GREATER AREA OF THE CORNEA

Photokeratoscopy, according to the type of instrument used, can measure 55 to 100 percent of the corneal surface.

ABILITY TO MEASURE THE CURVATURE OF THE PERIPHERAL CORNEA

Photokeratoscopy can measure the contour of the midperiphery and the far periphery of the cornea. Based on this information, one can design a lens that will approximate more accurately the IZ of the cornea. This is especially important if the cornea is very toroidal.

ABILITY TO MEASURE THE CURVATURE OF THE CENTRAL CORNEA

Photokeratoscopy can also measure the curvature of the central 1–3 mm of the cornea. This corresponds to the area that is usually measured by the ophthalmometer.

ABILITY TO DETECT SUBTLE TOPOGRAPHIC SHIFTS

Trauma can cause small, subtle changes in corneal topography which are best detected by photokeratoscopy.

ABILITY TO EVALUATE SURGICALLY INDUCED ASTIGMATISM

In refractive operations, surgically induced astigmatism can occur. The keratoscope provides a means for quantitatively measuring this change.

AVAILABILITY OF DATA

Hard-copy data are produced by keratoscopy. This is a distinct advantage, as the data are readily available for comparison with subsequent readings.

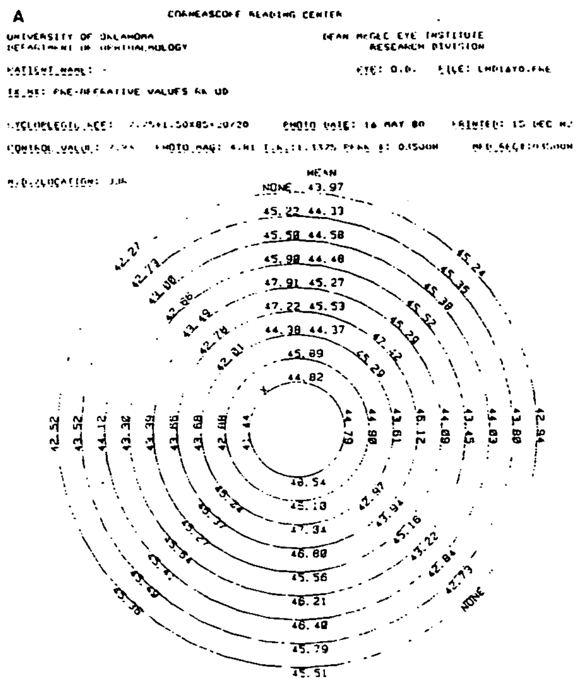
The corneoscope is a photokeratometer that reduces many of the calibration errors by presenting a hemispherical, lighted Placido disc image to the cornea (Color Plate 4-2). The observer focuses on a virtual image reflection (plus sign) from the patient's cornea apex. A photograph is taken. The resultant Polaroid photograph is analyzed in a comparator (Color Plate 4-3) on the Kera-scan* so that the radius of curvature of the cornea can be determined at any point.

Classification

Based on corneal topography as determined with the corneoscope, corneas have been categorized as follows.

ROUND CORNEA

A round cornea is one in which there is very little flattening of the peripheral cornea. There is less than 0.1 mm flattening of the radius of curvature from the center of the cornea to the periphery. An example of such a patient is shown in Color Plate 4-4. The corresponding computer-generated printout is shown in Figures 4-8A and 4-8B. Figure 4-8C is a demonstration of the computer graphics.



B

RING MEANS:

RING #	N	HALF CHORD (mm)	CONTROL RADIUS (mm)	PATIENT RADIUS (mm)	DELTA RADIUS (mm)	I.R. = 1.3375 PRE-OP POWER (d)	PATIENT POWER (d)	DELTA POWER (d)	I.R. = 1.376 PRE-OP POWER (d)	PATIENT POWER (d)	DELTA POWER (d)
1	8	2.87	7.960	7.46	0.50	0.00	45.33	45.33	0.00	50.50	50.50
2	8	4.67	7.960	7.47	0.49	0.00	45.25	45.25	0.00	50.41	50.41
3	8	6.69	7.960	7.61	0.35	0.00	44.38	44.38	0.00	49.44	49.44
4	8	8.31	7.960	7.42	0.54	0.00	45.54	45.54	0.00	50.71	50.73
5	8	10.21	7.960	7.46	0.50	0.00	45.27	45.27	0.00	50.43	50.43
6	8	11.99	7.960	7.59	0.37	0.00	44.49	44.49	0.00	49.56	49.56
7	8	13.79	7.960	7.58	0.38	0.00	44.50	44.50	0.00	49.67	49.67
8	8	15.62	7.960	7.62	0.34	0.00	44.31	44.31	0.00	49.39	49.39
9	6	17.48	7.960	7.68	0.28	0.00	43.97	43.97	0.00	48.99	48.99

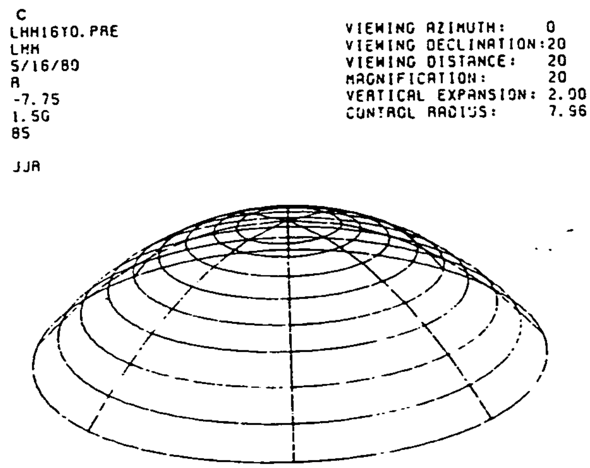


Fig. 4-8. (A) Computer-generated printout. The vertical third ring has a mean value of 44.37 D. (B) Computer summary of corneoscope ring means. The peripheral ninth ring is only 0.07 mm flatter than the central third ring. (C) Computer graphics of round cornea.

The third ring of the central cornea has a mean† dioptric value of 44.37 (Fig. 4-8A). The ninth ring of the peripheral cornea has a mean dioptric value of 43.97. When eight radials are measured on all rings, the peripheral ninth ring, with a radius of 7.68 mm, is only 0.07 mm flatter than the 7.6-mm central third ring (Figure 4-8B). There is thus only minimal flattening of the peripheral cornea.

The patient described in Figure 4-8 was myopic. The refractive reading was

$$-7.75 + 1.50 \times 85°$$

The patient obtained only 4.00 D of refractive change with radial keratotomy.

APLANATIC CORNEA

An aplanatic cornea is one in which there is considerable flattening of the peripheral cornea. There is more than 0.1 mm flattening of the radius of curvature from the center of the periphery. An example of such a patient is shown in Color Plate 4-5. The mean horizontal value of the central third ring is 42.00 D (Fig. 4-9A). The mean value of the peripheral ninth ring is 40.97 D. There is thus a significant change in the radius of curvature, from 8.04 mm centrally to 8.24 mm in the periphery, a change of 0.20 mm (Fig. 4-9B). Since there is considerable flattening of the cornea from the center to the periphery, this is designated as an aplanatic cornea.

The patient described in Color Plate 4-5 was myopic. The refractive reading was

$$-9.75 + 1.75 \times 90°$$

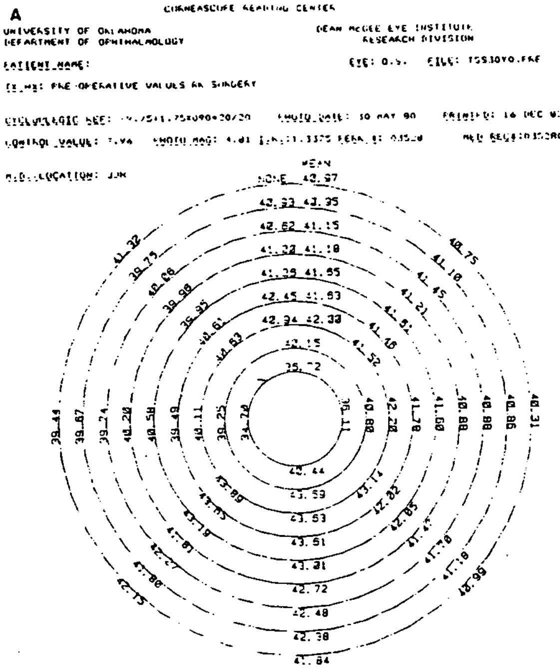
Radial keratotomy was performed. After two years, the patient has only 0.25 D of spherical refractive error. Thus 9.5 D of correction was obtained.

PHYSIOLOGIC VARIABLES THAT INFLUENCE TOPOGRAPHIC MEASUREMENTS

Since normal physiologic variables can result in changes in corneal topography, it is difficult to obtain consistent measurements.[10] These variables include sex, age, intraocular pressure, tear film thickness and corneal hydra-

† In photokeratoscopy, it is possible to arrive at a mean dioptric power of a given corneal area. The "mean" dioptric power is the average of all eight readings along a given ring. For example, in Figure 4-8B, the average of all eight readings, on the third ring, is 44.37; this is recorded on the "mean power" column. By contrast, the mean dioptric power of the ninth ring is 43.97. Thus minute levels of corneal dissymmetry may be delineated.

A



B

RING MEANS:

RING #	N	HALF-CHORD (mm)	CONTROL RADIUS (mm)	PATIENT RADIUS (mm)	DELTA RADIUS (mm)	I.R. 1.3375 PRE-OP POWER (d)	I.R. 1.3375 PATIENT POWER (d)	I.R. 1.3375 DELTA POWER (d)	I.R. 1.376 PRE-OP POWER (d)	I.R. 1.376 PATIENT POWER (d)	I.R. 1.376 DELTA POWER (d)
1	8	3.59	7.780	9.34	-1.38	0.00	36.22	36.22	0.00	40.35	40.35
2	8	5.13	7.960	8.21	-0.25	0.00	41.18	41.18	0.00	45.88	45.88
3	8	7.06	7.980	8.04	-0.08	0.00	42.01	42.01	0.00	46.80	46.80
4	8	9.07	7.980	8.12	-0.16	0.00	41.63	41.63	0.00	46.38	46.38
5	8	11.10	7.960	8.11	-0.15	0.00	41.66	41.66	0.00	46.41	46.41
6	8	12.99	7.980	8.20	-0.24	0.00	41.18	41.18	0.00	45.88	45.88
7	8	14.93	7.980	8.21	-0.25	0.00	41.15	41.15	0.00	45.84	45.84
8	8	16.84	7.960	8.24	-0.28	0.00	40.96	40.96	0.00	45.63	45.63
9	7	18.62	7.980	8.24	-0.28	0.00	40.97	40.97	0.00	45.64	45.64

Fig. 4-9. (A) Computer-generated printout. The third ring has a mean value of 42.00 D (B) Summary of corneoscope ring means. The peripheral ninth ring is 0.20 mm flatter (8.04 mm–8.24 mm) than the central third ring.

tion, ambient temperature, diurnal shifts, state of the pupil and ciliary body relaxation, eyelid tumors, squeezing of the eyelids, and corneal pathologic states.

SEX AND AGE

There is a difference in corneal curvature based on sex.[15] Female patients demonstrated a central power of 44.25 D, plus or minus 1.43 D, with a median of 44.25 D. Male patients revealed a central power of 43.38 D, plus or minus 1.53 D, with a median of 43.37 D.

Age is also a factor. The cornea at birth has a steep curvature that gradually flattens between one and six years of age.[15,16] The female cornea flattens more slowly than the male cornea.[15] In addition to flattening, a small amount of astigmatism develops between the ages of one and six years. Woodruff[15] found that 7.75 percent of the patients demonstrated 0.25–0.75 D of with-the-rule astigmatism, and 4.03 percent demonstrated against-the-rule astigmatism over 0.75 D. Another finding was that the total corneal power was very large at birth but gradually decreased, by 0.044 D a year, between the ages of one and six years. In Mandell's study,[16] it was demonstrated, using a portable photokeratoscope, that the cornea has a shorter radius in the infant than in the adult.

Color Plate 4-1: Corneoscope photograph. Keratoconus with displaced corneal apex. Small arrow corresponds to visual axis (which is at center of pupil). The "dot" (which is the "light reflex") corresponds to the high spot of the cornea in front of the large arrow.

Color Plate 4-2. Corneoscope photokeratoscopy of a cornea.

Color Plate 4-3. Comparator used for analysis of a corneoscope photograph. (Kerascan)§

Color Plate 4-4: Corneoscope photograph. The cornea is round. There is little flattening of the peripheral cornea.

Color Plate 4-5: Corneoscope photograph. The cornea is aplanatic. There is definite flattening of the peripheral cornea.

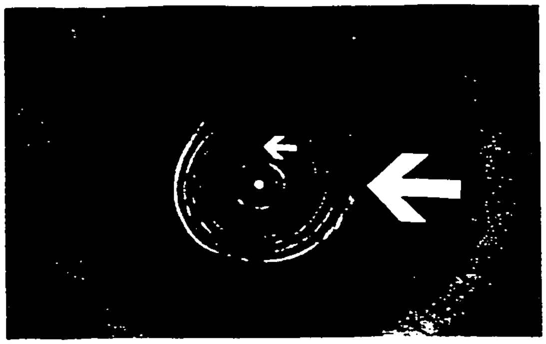
INTRAOCULAR PRESSURE

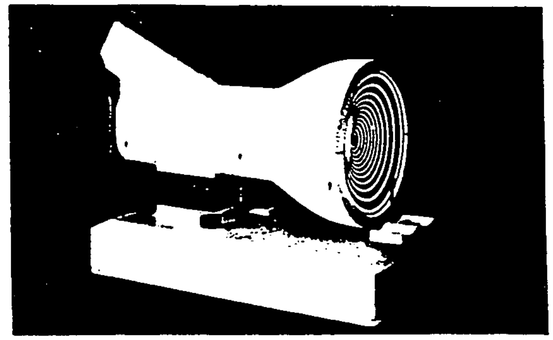
Intraocular pressure does not appear to alter significantly the corneal curvature of normal eyes. Using eye bank eyes, one of the authors (J.J.R.) found that when the intraocular pressure was raised to 40–60 mm Hg, there was no effect on corneal curvature.

TEAR FILM THICKNESS AND CORNEAL HYDRATION

Shortly after one awakens, the tear film thins due to evaporation. With thinning, the tear film becomes more hypertonic, and so exerts an osmotic effect, drawing fluid out of the cornea. The cornea may thin as much as 4 percent in the first hour after eye opening.[17,18] Since the tear film is the source of reflection for photokeratoscopy and keratometry, changes in tear film thickness will be manifested as localized changes in the radius of curvature of the ocular surface.

§ Kera Corporation, Santa Clara, California.


4-1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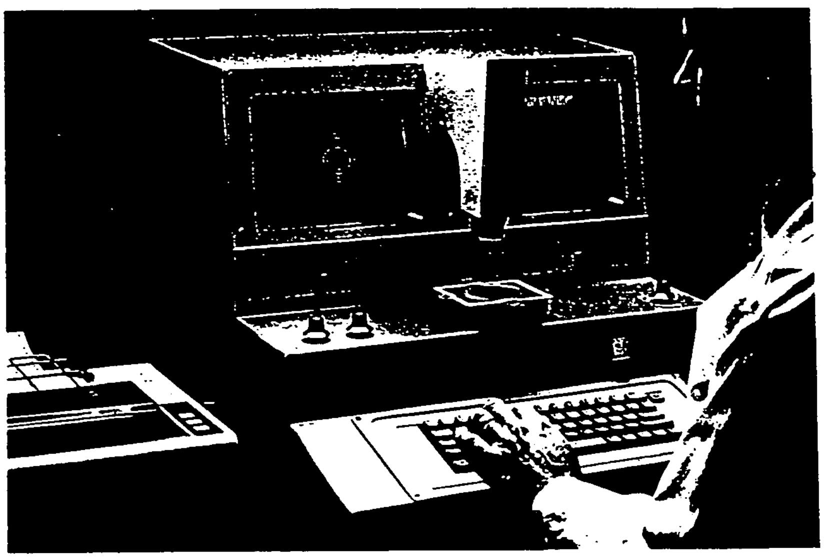
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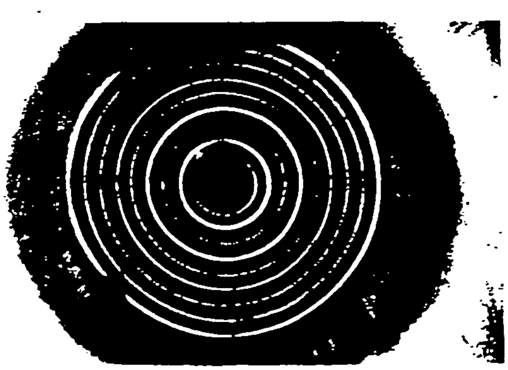
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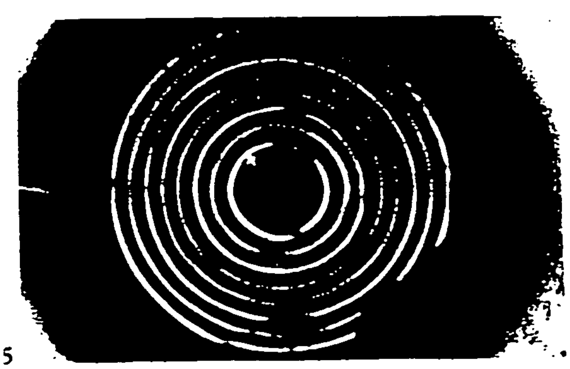
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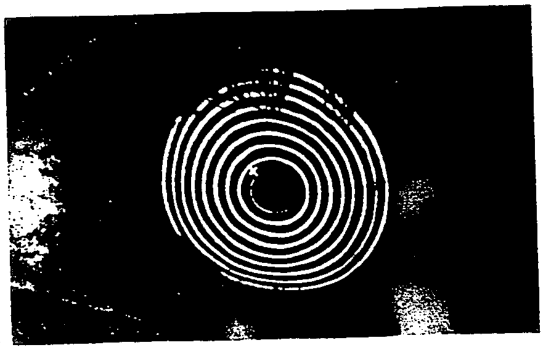
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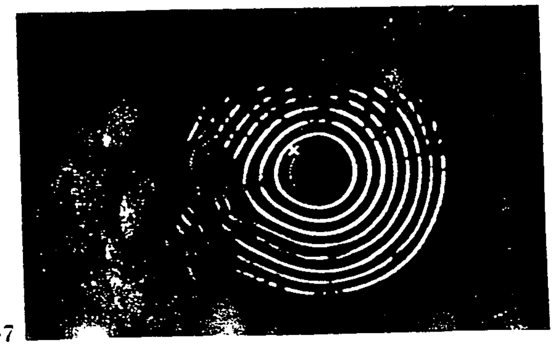
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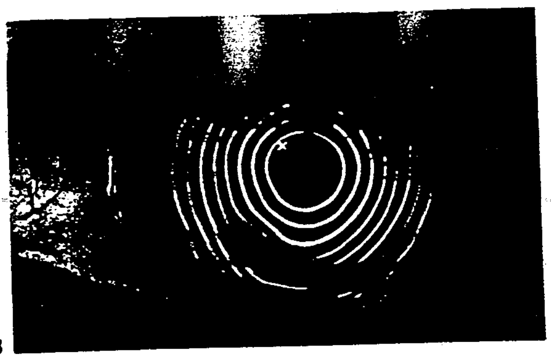
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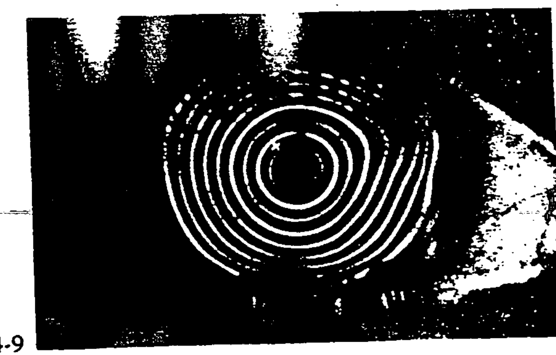
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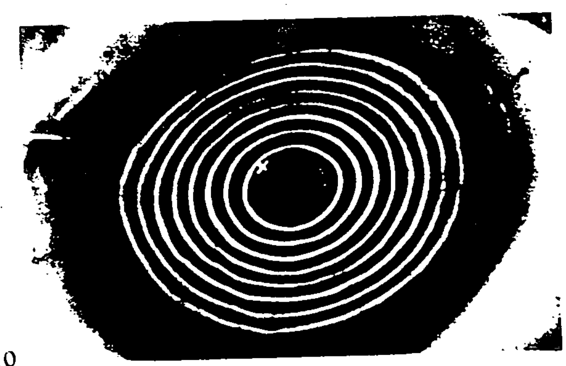
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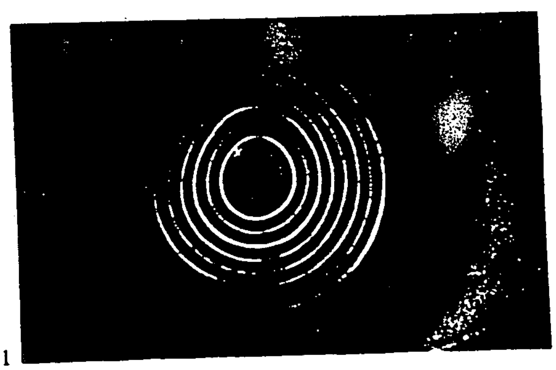
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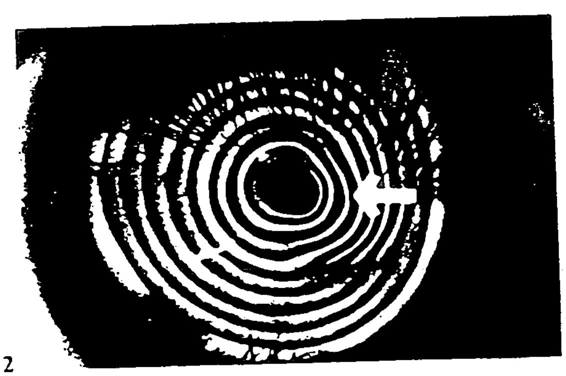
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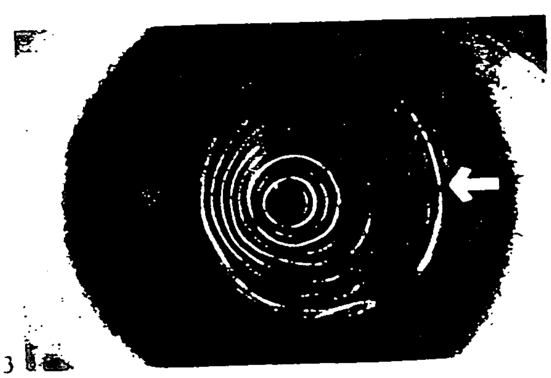

4-13

Color Plate 4-6: Pellucid marginal degeneration. Excessive flattening in the 90° meridian.

Color Plate 4-7: Corneoscope photograph. Pterygium. Bulk of pterygium causes corneal flattening.

Color Plate 4-8: Corneoscope photograph. Rheumatoid corneal furrow.

Color Plate 4-9: Corneoscope photograph. Scleral nodule.

Color Plate 4-10: Corneoscope photograph. With-the-rule astigmatism. Due to steepness of the vertical corneal meridian, there is a narrower ring separation in the vertical meridian.

Color Plate 4-11: Corneoscope photograph. Against-the-rule astigmatism following cataract extraction. Due to flattening of the vertical corneal meridian, there is a wider ring separation in the vertical meridian.

Color Plate 4-12: Corneoscope photograph. Moderately advanced keratoconus of the left eye. Tear drop or pear-shaped central ring (arrow). The central rings elongate vertically and inferior-temporally. The mid-periphery rings steepen in the inferior temporal quadrant.

Color Plate 4-13: Corneoscope photograph. Very advanced keratoconus. The central area is so steep that it is difficult to approximate with a contact lens. The peripheral ninth ring (arrow) is used to select the base curve of the contact lens.

This dehydration may be exacerbated in the dry eye state. In a randomly selected group[19] of 94 patients from a single contact lens practice, 65 patients with no complaints of dry eyes demonstrated a 7.1-mm radius of curvature (44.02 D); these patients had a Schirmer test result of 15.1 mm. Twenty patients complaining of dry eye symptoms demonstrated a flatter radius of 7.75 mm (43.54 D) in both meridians; these patients had a Schirmer test result of 12.9 mm. The drier cornea was approximately 0.5 D flatter than the more hydrated corneal surface.

TEMPERATURE

The temperature of the environment may further contribute to dehydration of the cornea and subsequent changes in its shape. Patients transferring from an outdoor temperature of 90°F to an indoor air-conditioned temperature of 72°F showed such changes. For one and one-half hours, the peripheral corneal radii of curvature were 0.1-0.4 mm longer (flatter) in the warmer environment. This suggests that the higher temperature causes dryness. Such dryness is associated with flattening of the cornea analogous to that of the postawakening state. Similar changes in the curvature of the cornea occurred when subjects were placed under a hair dryer with warm air blowing over the face. Although the central corneal curvature did not change, peripheral flattening occurred approximately 3.5 mm from the apex.[20]

DIURNAL SHIFTS

Significant shifts in measurements can occur throughout the day. In an experiment, topographic analysis was done on three consecutive days, with three photographs being taken at each sitting. These sittings occurred every hour for 15 hours. The photokeratoscopic readings varied according to the area of the cornea. In the central area, as well as in the paracentral area, there were no significant changes in the curvature during the day. By contrast, in the periphery, significant change occurred.[20] In 730 patients, or 73 percent of those observed with photokeratoscopy, there was a change in the cornea in the peripheral zones between awakening and 9:00 in the evening. The readings in peripheral zones had a flatter radius of curvature early in the morning (by 0.4 to 0.6 mm) and became steeper until they reached their maximum steepness around 4:00 P.M. The peripheral curves then flattened until they reached the baseline morning reading at approximately 9:00 P.M.

These topographic shifts are important in contact lens fitting, for tight lens symptoms will occur if the cornea becomes flatter than the flattest peripheral contact lens curve. If the patient is fitted in the afternoon, the corneal curvature will be steep. A lens that approximates the cornea in the afternoon may be too steep the following morning. This could be the cause of early-morning tight lens symptom.

STATE OF THE PUPIL AND CILIARY BODY RELAXATION

The state of the pupil and ciliary body relaxation do not significantly affect corneal topography. Keratometric readings are apparently unaffected by cycloplegics or anesthetics. In 100 subjects, no changes in curvature were noted up to 60 minutes after instillation of 1 percent cyclopentolate or 10 percent phenylephrine, with or without anesthetic agents.[21]

By contrast, convergence can cause a shift in the dioptric power of the cornea. In one study,[22] convergence was associated with flattening of the cornea in the horizontal

meridian, apparently linked to stimulation of the medial rectus. This resulted in a power shift of approximately 0.2 D in the cornea. In contrast to the horizontal meridian, the vertical meridian does not change during convergence.

Corneal power changes during convergence, but not during accommodation.[23] If the object of regard is placed in the sagittal plane, stimulating convergence, a corneal power shift is noted in the horizontal meridian. If accommodation alone is stimulated without convergence, however, no corneal power shift is realized. This alteration in the horizontal meridian has been noted in nonpresbyopic eyes only and may account for a shift in astigmatism against-the-rule with age.

SQUEEZING OF THE EYELIDS

Squeezing of the eyelids may be associated with corneal topographic changes. One investigator,[24] studying 10 patients with blinking, demonstrated a 10.3-mm Hg rise. With a tight lid squeeze, the pressure rose to 51 mm Hg. In one study,[25] there was a 9.0-mm Hg elevation of pressure following lid squeezing. The changes in corneal topography following lid squeezing may reflect indentation phenomena instead of simple intraocular pressure elevation.

Prolonged near work, associated with convergence and eyelid pressure, can cause changes in corneal topography. In one study, a 20-year-old college student had a complaint of diplopia following near work.[26] The individual was examined before reading, and photokeratoscopy was repeated after one and one-half hours of continuous reading. Additional photographs were taken an hour after cessation of reading. Lid pressure indentations of the cornea, above and below the visual axis, were compatible with the lid position. This area of distortion returned to a normal contour one hour after cessation of reading. Ray tracing from the calculated degree of asphericity with the photokeratometer suggested that the presence of the second image could account for the diplopia.

EYELID TUMORS

Congenital and developmental eyelid tumors may be associated with astigmatic changes.[27] This is due to pressure on the cornea. Hemangiomas of the upper lid can cause plus cylinder power in the axis of the corneal pressure.[24] This irregular, or fluctuating, astigmatism must be carefully evaluated to preclude the development of amblyopia in the infant.

Chalazia of the eyelids are another common source of astigmatism due to pressure on the cornea.

Fig. 4-10. Salzmann's nodular dystrophy. Corneoscope photograph. There is irregularity in the superior nasal quadrant of the patient's left eye.

CORNEAL PATHOLOGIC STATES

Corneal pathologic states are associated with frequent alterations of corneal curvature.

Salzmann's Nodular Dystrophy

It has been the experience of one of the authors (J.R.) that in some instances of Salzmann's nodular dystrophy (Fig. 4-10), the mid-periphery of the cornea is very irregular. Such patients are difficult to fit with soft lenses. Hard lenses are often necessary.

Pellucid and Terrien's Marginal Degenerations

Pellucid marginal degeneration is characterized by thinning of the interior perilimbal corneal tissue. The thinned and weakened inferior cornea bulges forward causing excessive flattening of the cornea in the 90° meridian (Color Plate 4-6). Analysis of the topographic effects of the thin portion of the cornea can be helpful in determining the approach toward surgical correction.[28]

Similar topographic effects are seen in Terrien's marginal degeneration. In Terrien's marginal degeneration, the thin portion of the cornea is superior, which causes flattening along the 90° axis. These changes can be easily demonstrated and therapeutic approaches can be based on the topographic analysis using corneoscopy.[29,30]

Pterygium

A pterygium is a fibrovascular growth of conjunctival tissue over the corneal surface. In an advanced pterygium, corneal flattening occurs due to the bulk of the tissue (Color Plate 4-7), with resultant astigmatism.

Rheumatoid Furrows and Scleral Nodules

Occasionally, inflammatory diseases of the cornea and sclera can cause alterations in corneal topography. Rheumatoid corneal furrows that occur in a crescentric pattern 1–2 mm in from the limbus, most typically inferiorly, can produce similar effects to relaxing incisions in that flattening of the cornea occurs in that meridian (Color Plate 4-6). Similarly, inflammatory disease of the conjunctiva, such as a rheumatoid scleral nodule, can cause peripheral flattening with central steepening as a result of the comprehensive effect of the mass lesion (Color Plate 4-7). With healing of the rheumatoid furrow, the degree of flattening may decrease as the tissue fills in; however, frequently there is resultant irregular astigmatism, which may affect visual acuity. In general, when a scleral nodule resolves, the effect of the central induced corneal astigmatism is diminished.

CONTACT LENS FITTING

Most practitioners fit contact lenses on the basis of keratometric readings of the central cornea, the diameter of the cornea, and the width of the interpalpebral fissure. Topographic keratometry of the peripheral cornea is used only in problem cases. An evaluation of peripheral corneal topography[7,22] prior to contact lens fitting, however, can be useful. Such an evaluation alerts the physician to potential areas of corneal touch and to the size of the optical zone (OZ) required to achieve a precise fit. This information, provided by the corneoscope, has been very helpful in contact lens fitting.[28]

The comparator allows the clinician to determine the radius of curvature of any corneal point and to perform a "trial fit" of the patient's cornea to determine potential tight and loose spots from the Polaroid corneoscope photograph (Fig. 4-11). The corneal photograph of the Placido disc rings if projected in the comparator, and the necessary base curves are determined.

If a contact lens fits the central cornea well but pressure points are recognized with fluorescein, the clinician will frequently flatten the lens to decrease these pressure sites. Figure 4-11 shows the image of the comparator overlying the lighter rings of the corneoscope photograph. The comparator allows the photographic image (4.81X) to be enlarged (5X) until the ring images precisely match the screen image. In this fashion, the radius of curvature of the cornea in any meridian, and its subsequent dioptric power at any position across the cornea, may be determined. Note that the white rings from the corneoscope photograph lie precisely beneath the black rings in the horizontal meridian. By contrast, in the vertical meridian

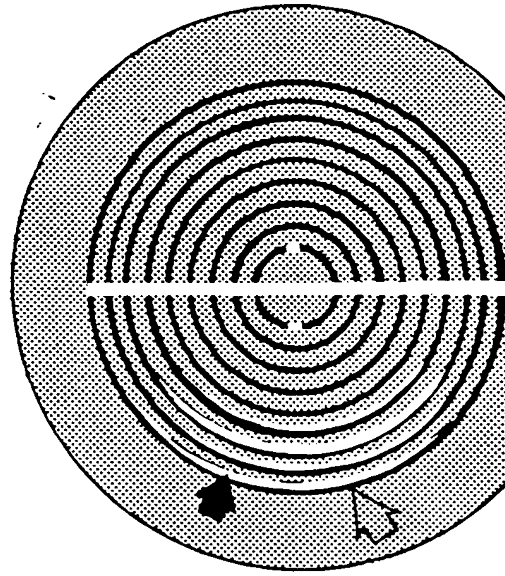


Fig. 4-11. Comparator. The white rings of the corneoscope photograph have a shorter chord length inferiorly on rings two through nine. In all other areas, the white rings of the corneoscope match the black face plate rings of the comparator.

at the 6 o'clock position, the white rings from the corneoscope photograph are above the black rings. This indicates that the vertical radius of curvature is shorter (steeper cornea) than the horizontal meridian. This is manifested by a shorter chord from the center of the photograph to the 6 o'clock position. There is thus greater dioptric power, which will be analyzed as greater corneal power at 6 o'clock. The Placido disc map topography of the corneoscope allows the observer to analyze the photograph promptly in a manner analogous to the analysis of map topography. The comparator simply allows quantification of this analysis.

STEEP CORNEA

Large Amount of with-the-rule Astigmatism

With a steep cornea, there is a short chord length and so a narrower ring separation. Color Plate 4-10 demonstrates with-the-rule astigmatism. Since the cornea is steeper in the vertical meridian, there is a narrower ring separation vertically. A small degree of with-the-rule astigmatism in the peripheral cornea is valuable in contact lens fitting. The contact lens will normally rock over the flatter 3 o'clock and 9 o'clock corneal positions and allow tear

flow beneath the lens at the 6 o'clock position, where the contact lens is far flatter than the cornea. If a single flat area of the cornea is unrecognized, however, and the contact lens is inadvertently fitted more steeply in this quadrant, the contact lens can be expected to decenter toward the opposite side of the cornea. This contact lens decentration can be ameliorated in most cases by making the peripheral curve flatter than the flattest central curve. A peripheral curve 0.04–0.05 mm flatter than the peripheral cornea will allow for adequate lens rocking and tear exchange.

Large Amount of against-the-rule Astigmatism after Cataract Surgery

After cataract surgery, if wound gape occurs in the 12 o'clock incisional area, a large amount of peripheral against-the-rule astigmatism may occur. Color Plate 4-11 demonstrates against-the-rule astigmatism. Since the cornea is flatter in the vertical meridian (incisional area), there is a wide ring separation vertically. In this instance, the contact lens decenters, with consequent displacement of the contact lens inferiorly. Aphakic contact lens decentration warrants careful Placido disc analysis of the peripheral cornea. Unfortunately, with a long corneal chord vertically, it is difficult to fit a lens flatter than the flattest cornea without apical touch and consequent discomfort. Wound revision may be necessary before a contact lens can be adequately fitted.

POSTKERATOPLASTY ASTIGMATISM

Corneal topography after penetrating keratoplasty can be quite altered. Occasionally, even when central keratometric readings demonstrate very little astigmatism, the altered peripheral topography at the wound interface may preclude the fitting of contact lenses. In general, contact lenses on these corneas, because of steep falloff inferiorly, tend to ride low and to move temporally. By using photokeratoscopy, the area of altered pathology can usually be determined and contact lens designs specifically made to vault the area of pathology. Unfortunately, this altered peripheral corneal topography often makes fitting contact lenses extremely difficult or uncomfortable for the patient and so necessitates the use of a relaxing incision, wedge resection, or wedge addition operation to correct the pathologic corneal topography.

KERATOCONUS

Keratoconus often demonstrates steepening in the inferior temporal quadrant. This is manifested by a shorter chord length in this area and a pear- or teardrop-shaped central ring as demonstrated by the corneoscope (Color Plate 4-12) and the computer-generated printout (Fig. 4-12). In the early stages of keratoconus, using keratometry, it is easy to fit a contact lens with good apical clearance. As keratoconus progresses, however, with spread of the cone centrally and then nasally, the cornea becomes steeper, so that contact lens fitting becomes increasingly difficult. It is difficult to design a lens with a central posterior curve (CPC) to approximate a 65.15-D cone. Such a lens is very steep, so there is peripheral touch. In advanced keratoconus one should therefore vault the cone and fit with the flattest peripheral curve. In Figure 4-12, the ninth horizontal ring at the 3 o'clock position has a radius of curvature of 6.64 mm or 50.79 D. A contact lens with this base curve, with sufficient sagittal depth to clear the apex of the cone, will be comfortable. As the central cornea continues to steepen, one must use the peripheral rings to select the base curve of the contact lens (Color Plate 4-13).

Sometimes when a contact [illegible] is fitted in keratoconus, the lens causes pressure on [illegible] of the cone, rocks over the cone, decenters inferiorly, indents the cornea, and so causes additional irregular astigmatism in the inferior half of the cornea. As previously mentioned, in keratoconus alone the irregularity is usually in the inferior temporal quadrant and not the entire inferior portion of the cornea. By analyzing the peripheral corneal topography, it is therefore possible to determine if the corneal irregularity is due to a poorly fit lens in keratoconus. The irregularity of contact lens-induced astigmatism is manifested by broadened or broken lines at pressure points. The subtle, early pear-shaped irregularity of the ring contour in keratoconus is overshadowed by the manifestations of contact lens-induced astigmatism. When the poorly fitting contact lens is removed, there is gradual symmetrization of the peripheral corneal mires, as demonstrated by photokeratoscopy. The clinician frequently finds it difficult using keratometric measurements alone to determine the most efficacious time for contact lens refitting. Simple analysis of the peripheral corneal topography eliminates this therapeutic difficulty. As the shape of the cornea returns to normal, the inferior flat mires become symmetrical and well defined, instead of broad and flat from pressure points.

CORNEASCOPE READING CENTER

UNIVERSITY OF OKLAHOMA
DEPARTMENT OF OPHTHALMOLOGY

DEAN McGEE EYE INSTITUTE
RESEARCH DIVISION

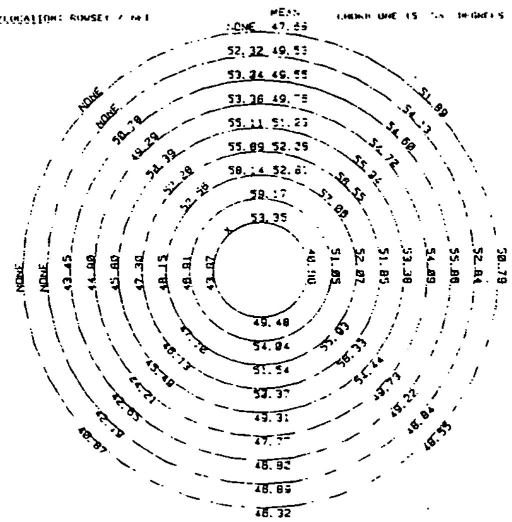
PATIENT NAME:

KERATOCONUS, AFTER CONTACT LENS FIT

CYCLOPLEGIC REF: [illegible] PHOTO DATE: 11/19/80

CONTROL VALUE: [illegible] PHOTO MAG: [illegible]

[illegible] LOCATION: [illegible]



RING MEANS:

					I.R. = 1.3375			I.R. = 1.376		
RING # N	HALF-CHORD (mm)	CONTROL RADIUS (mm)	PATIENT RADIUS (mm)	DELTA RADIUS (mm)	PRE-OP POWER (d)	PATIENT POWER (d)	DELTA POWER (d)	PRE-OP POWER (d)	PATIENT POWER (d)	DELTA POWER (d)
1 8	2.82	7.960	7.33	0.63	0.00	46.35	46.35	0.00	51.64	51.64
2 8	4.04	7.960	6.45	1.51	0.00	52.40	52.40	0.00	58.40	58.40
3 8	5.68	7.960	6.42	1.54	0.00	52.82	52.82	0.00	58.84	58.84
4 8	7.32	7.960	6.51	1.45	0.00	52.09	52.09	0.00	58.03	58.03
5 8	9.06	7.960	6.63	1.33	0.00	51.23	51.23	0.00	57.08	57.08
6 8	10.72	7.960	6.82	1.14	0.00	49.76	49.76	0.00	55.44	55.44
7 8	12.52	7.960	6.87	1.09	0.00	49.55	49.55	0.00	55.20	55.20
8 6	14.13	7.960	6.86	1.10	0.00	49.54	49.54	0.00	55.19	55.19
9 5	16.15	7.960	7.13	0.83	0.00	47.48	47.48	0.00	53.12	53.12

Fig. 4-12. Computer-generated printout. (A) The ninth horizontal ring at the 3 o'clock position has a radius of curvature of 6.664 mm or 50.79 D. (B) Summary of corneoscope ring means.

SUMMARY

Corneal topographic studies have demonstrated that the cornea is frequently spherical in the central area and aspherical in the peripheral area. There is gradual flattening of the cornea from the center to the periphery.

The amount and symmetry of peripheral flattening can vary. In some instances (round cornea), the amount of flattening is slight; in others (aplanatic cornea), it is considerable. This is an important observation, as ideally the curvature of the contact lens should approximate the mid-periphery of the cornea.

Corneal topography can be evaluated for the central cornea with the ophthalmometer. The peripheral cornea, however, must be evaluated with the photokeratoscope or corneoscope.

Many physiologic variables affect topogometric measurements. It is thus difficult to design a contact lens since corneal topography is so variable under even normal conditions.

Nevertheless, corneal topography is of great assistance in contact lens fitting, especially in problem cases such as steep corneas, large amount of astigmatism, and keratoconus.

ACKNOWLEDGMENT

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APPENDIX A LOCALIZATION OF VISUAL AXES

A microscopic light (or even a hand light), when directed toward the patient's cornea, emits light rays that are reflected by the cornea as if it were a convex mirror (Fig. 4-2). A ray (e.g., Ray 1) that has an oblique incidence to the cornea is reflected away from the observer. (The angle of incidence is equal to the angle of reflection.) A ray (e.g., Ray 2) that has a perpendicular incidence to the cornea is reflected back to the observer. Ray 2 is incident to a single point on the corneal surface which can be considered to be a minute plane mirror; the light ray is "normal" (perpendicular) to the cornea. This ray is assumed to be the visual axis. However, the visual axis corresponds to Ray 3; this is the light ray that passes directly to the fovea, and is the light that is observed by the patient. Thus, although Ray 2 is not the visual axis, since Ray 2 and Ray 3 are close together, as a matter of practicality, Ray 2 can be considered to be the visual axis. All of the preceding is based on a cornea that has a spherical surface. A different situation arises, however, if the corneal surface is highly irregular. In this instance, the light ray (e.g., Ray 4) is reflected from the highest point on the cornea, unrelated to the visual axis. There is no single point, adjacent to the visual axis, that provides a plano mirror so that the incoming ray will have perpendicular incidence. The "plano mirror" is tilted so the incoming ray now has an oblique incidence. When a ray has an oblique incidence, it is reflected away from the observer's eye. Thus is it not possible to use the reflected ray to localize the visual axis in highly irregular corneas.

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This chapter has a Self-Assessment Test; see the section Continuing Medical Education at the end of Volume 2.